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AN EXPERIMENT TO DETERMINE THE RELATION
BETWEEN DISSOLVED OXYGEN CHANGE IN PIPE-
LINE FLOW AND REYNOLDS NUMBER

Harry Stierli, et al

Public Health Service
Cincinnati, Ohio

December 1963

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**NATIONAL WATER QUALITY NETWORK
APPLICATIONS AND DEVELOPMENT REPORT**

#8

**An Experiment to Determine the Relation
Between Dissolved Oxygen Change
In Pipeline Flow and Reynolds Number**

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Division of Water Supply and Pollution Control
U. S. Public Health Service
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RECOMMENDATIONS

On the basis of material in this report, the following recommendations are made concerning future design of pump and pipeline systems for obtaining representative samples from surface water courses:

1. Sampling systems should be designed to pump the water from the stream through the pipeline at or above a Reynolds number of 25,000 to minimize change in dissolved oxygen concentration.
2. This study reconfirms the special need for river cross-section measurements of dissolved oxygen where an automatic monitoring sampling intake is to be installed. The intake should be located to give a sample which most nearly reflects the character of the stream.

SUMMARY

Water samples for dissolved oxygen measurements were collected at the intake and discharge of two submersible pumping systems at the Little Miami River Field Test Station during July and August, 1963. One pumping system consisted of a 1/3 hp submersible pump in the river with 400 feet of 3/4" polyethylene piping to a discharge header in the Field Test Station. The other system was similar with a 1 hp pump and 400 feet of 1-1/4" polyethylene piping. Flow rates through the piping were varied to study the effect of dissolved oxygen change over a range of Reynolds numbers from 2,000 to 30,000. There was a 0.2 mg/l reduction in dissolved oxygen concentration for the highest Reynolds number and larger reductions as the flow was decreased. The amount of oxygen-consuming material in the water and pipeline appeared to affect the change in concentration. A Reynolds number of 25,000, or higher, assured a minimal change in dissolved oxygen.

Cross-section measurements indicated a small gradient in dissolved oxygen across the river. Variations in shape and slope of this gradient occurred during the study. The average value for the dissolved oxygen occurred at a point where the river was the deepest (approximately four feet deep during the test period). Within the limits of measurement, there was no variation along this cross-section in temperature or conductivity.

INTRODUCTION

Automatic water quality monitoring generally is done in two ways: (1) Taking the sensors of the instruments to the water, and (2) bringing the water to an instrument system. There are advantages and disadvantages to both ways, but at the present time, the latter is preferred. This necessitates a system consisting of an intake, pump, pipeline and discharge. In previous work,¹ it was indicated that the dissolved oxygen content of the water can be changed drastically by a jet pump system. Also, under certain flow conditions, there can be a significant change in the amount of dissolved oxygen as the water travels from a submersible pump intake through piping to a discharge point in a field station.

The purpose of this experiment was to obtain data that would help to establish operating conditions for satisfactory water sampling. For practical reasons, the experiment was divided into two parts. The first was to measure temperature, dissolved oxygen concentration, and conductivity of the Little Miami River in cross-section at the Field Test Station. This would show if the river was homogenous, or if these water quality parameters change as a function of the sampling point. In addition, this would help to determine the best location in the river for the intake.

¹WEEKS, JOHN D., "A Preliminary Report on the Effect of Pump and Pipe Systems on Dissolved Oxygen Concentration". National Water Quality Network Applications and Development Report #7, January 1963.

The second part of the experiment was to measure dissolved oxygen changes in intake and discharge samples with different pipeline flow conditions. The primary objective was to determine a Reynolds number² that would permit satisfactory operation. This information will be used in the design of sampling systems.

²The Reynolds number (R) is a ratio of inertial forces to the viscous forces existing in a moving fluid. In general, laminar flow always exists below a Reynolds number of 2000 and turbulent flow exists above 4000. The range 2000-4000 is a transitional zone. Laminar flow has been observed with Reynolds numbers as high as 100,000 but these are special cases. The number is dimensionless and may be calculated from the following equation:

$$R = \frac{VD}{\nu}$$

where R = Reynolds number

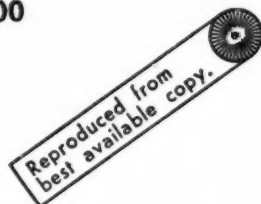
V = Velocity in feet per second.

D = A geometric length in feet. For pipes the diameter is used.

ν = Kinematic viscosity in sq. ft. per sec.

A numerical example for this experiment follows: Flow through the 1-1/4" diameter piping was measured as 11.3 gpm (0.025 cfs). The diameter of this piping is 0.104 ft. and the cross-sectional area 0.085 sq. ft. Therefore, the velocity of flow is $0.025/0.085 = 2.95$ ft. per sec. Kinematic viscosity of water at 25°C is approximately 0.000010 sq. ft. per sec. Hence, Reynolds number for this condition is:

$$R = \frac{2.95 \times 0.104}{1.0 \times 0.000010} = 30,000$$



EXPERIMENTAL APPARATUS AND SAMPLING TECHNIQUE

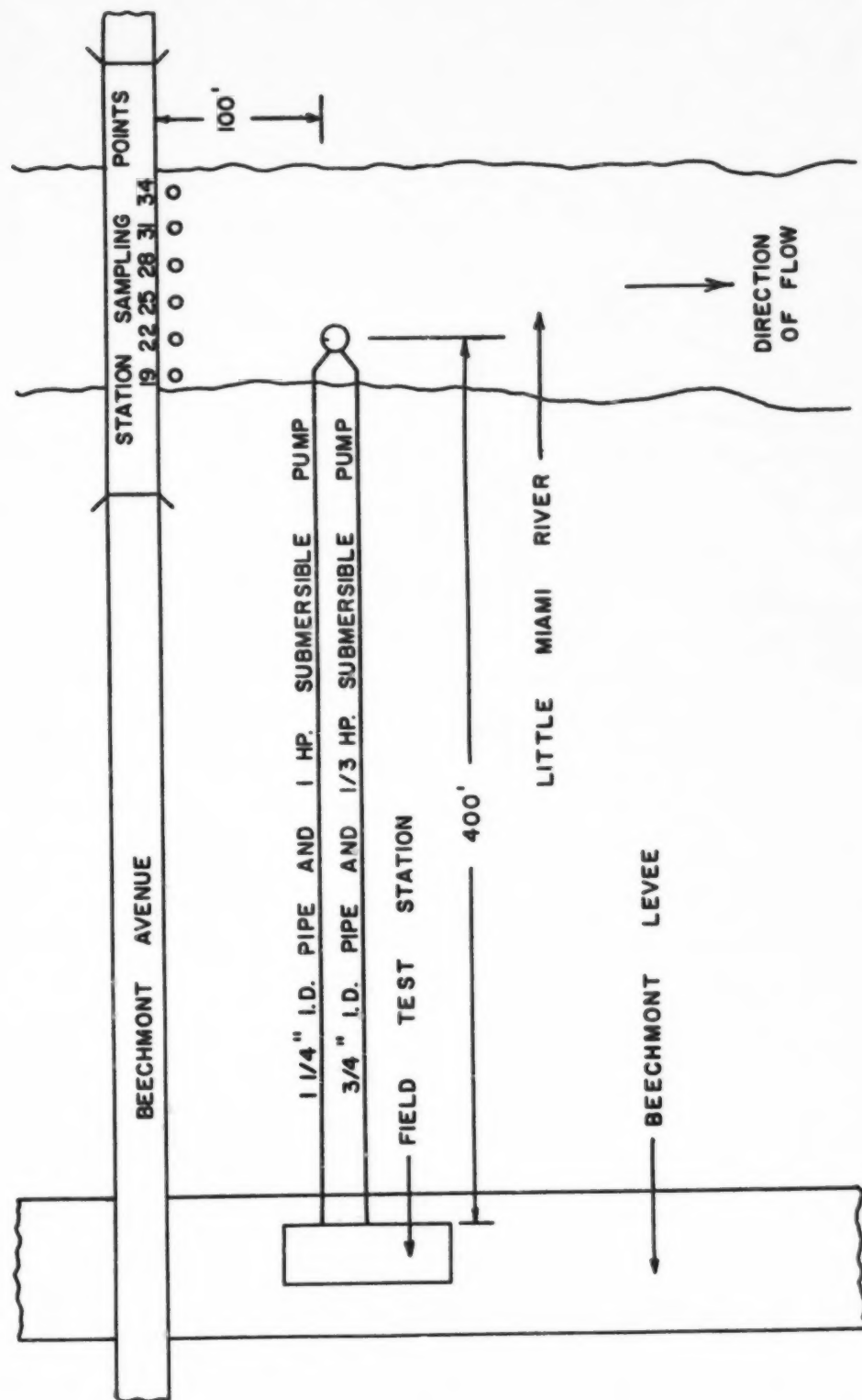
For the cross-section part of the experiment, the river was divided into a grid cross-section so that measurements could be taken at known points. The river was surveyed to give the elevation of the ground on a line across the river. This was approximately perpendicular to the direction of flow. The surveyed data is included in the Appendix, Page 19.

Grab-samples of the river were taken from the Beechmont Avenue Bridge for measurement of temperature, dissolved oxygen concentration and conductivity. Although this bridge is about 100 feet upstream from the present pump intakes, it was felt that this was close enough for comparison measurements. Figure 1 shows the relative location of station sampling points and the pump intakes.

Measurements along this cross-section were made at specific points from the bridge with reference to hand-rail supports on the downstream side of the bridge. These were numbered consecutively, beginning with the one closest to the Field Test Station and continued across the bridge. They are 11 feet apart and are referred to as stations.

Temperature was measured with a mercury thermometer with graduations of 1°F. An Industrial Instruments Solu Bridge, Model No. RB2-338 was used to measure conductivity. The Winkler method with alkaline azide modification was employed for dissolved oxygen measurement.

FIGURE 1. SCHEMATIC DIAGRAM OF LITTLE MIAMI RIVER SAMPLING SITE



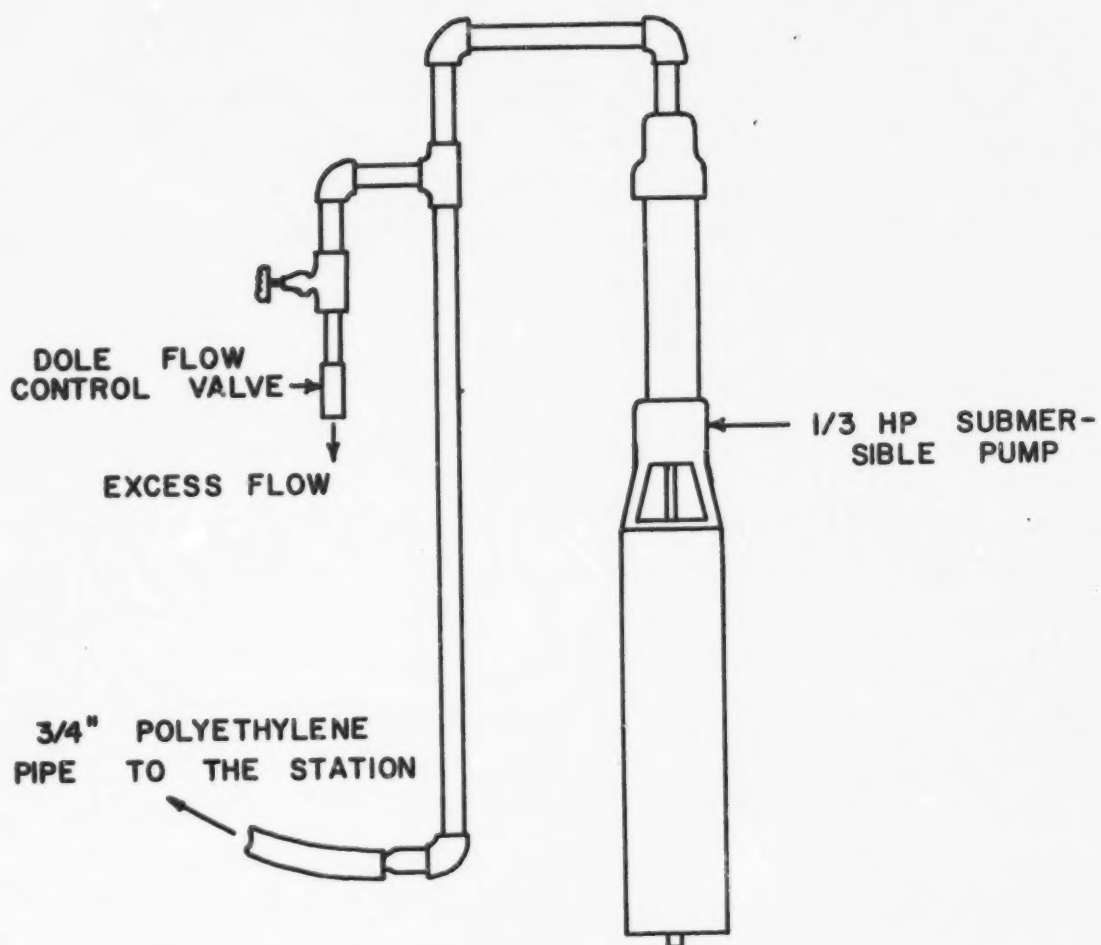
Based on previous experience, it was decided that a sampling time of early in the morning or late in the afternoon would give the best results. From 6 to 8 AM and 4 to 6 PM, the temperature and dissolved oxygen are the most stable. This decision was later changed to include data at different times during the day.

For the second part of the experiment, a pumping system, consisting of a 1/3 hp submersible pump, 400 feet of 3/4" polyethylene pipe, and a discharge manifold for collecting samples, was installed as shown on Figure 2. The pump was capable of pumping about three and one-half gallons of water per minute through the system. With this rate of flow, the water traveled from the river to the Field Test Station in approximately two minutes. A valve was installed next to the pump so that the amount of water flowing through the pipeline could be varied from three and one-half gpm down to zero gpm. Volumetric measurements of the flow were made using a bucket and a stop watch.

Data on dissolved oxygen changes from a pump intake in the river to a discharge manifold in the Field Test Station was also secured with a pumping system comprising a 1 hp submersible pump, 400 feet of 1-1/4" polyethylene pipe and discharge manifold as shown in Figure 1.

Measurements of the change in the dissolved oxygen were made in the following manner: The flow rate was held constant for a period of time while parallel samples were

FIGURE 2.
PUMP ASSEMBLY



taken from the river and at the discharge manifold in the Field Test Station. In the beginning, parallel measurements for the pipeline flow were collected from the middle of the bridge and in the Field Test Station. This was later changed to taking the river sample adjacent to the pump intake for better accuracy in the comparison. After sufficient data had been collected for one condition, the flow rate was decreased to obtain another set of data.

RESULTS OF EXPERIMENT

The dissolved oxygen data collected from the river cross-section is shown on Table 1. As expected, some variation in dissolved oxygen concentration occurred across the river although this variation was small and was not the same from day to day. For example, on July 25, there was an insignificant range of ± 0.1 mg/l from the computed average; whereas on August 8, the range was ± 0.5 mg/l from the average. The data from this cross-section was averaged to find a representative value for dissolved oxygen (see Appendix, Page 20, for sample calculation). This averaging was approximated by dividing the river into sections. The DO value in each section was multiplied by the area of the section. These products were added and then divided by the total area. This data is shown on Table 2. The average values consistently occurred at a point very near where the river was the deepest (approximately four feet deep during the test period).

The dissolved oxygen gradient seemed to follow three general patterns. In the first, the dissolved oxygen increased linearly across the stream. In the second, the DO would start at a low value, increase to a peak near the middle of the stream, and then decrease and level off on the other side. The third pattern started low and would stay low until, near the middle, the DO would make a step increase and continue high across the stream. These patterns are illustrated in Figure 3.

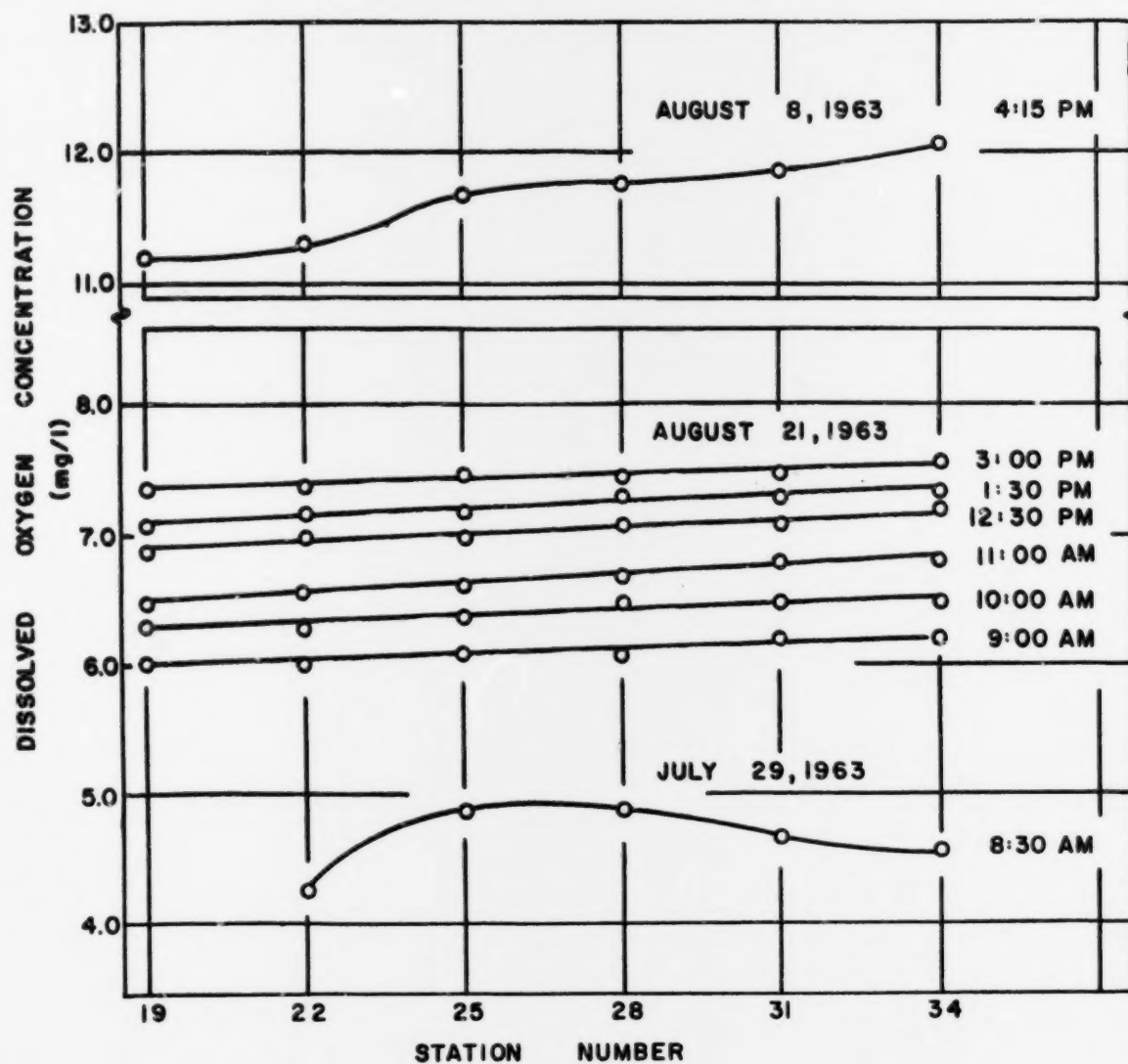
TABLE 1. CROSS-SECTION DISSOLVED OXYGEN DATA

Date 1963	Station Number						Time
	19	22	25	28	31	34	
7/25		7.1	7.3	7.2	7.2	7.1	6:30 AM
7/26		8.6	8.6	8.6	8.6	8.6	9:30 AM
7/29		4.3	4.9	4.9	4.7	4.6	8:30 AM
8/8	11.2	11.3	11.7	11.9	11.9	12.1	4:15 PM
8/13	6.1	6.2	6.7	6.9	6.9	7.0	11:00 AM
8/15	7.7	7.7	7.8	7.9	8.0	8.1	10:30 AM
8/21	6.0	6.0	6.1	6.1	6.2	6.2	9:00 AM
"	6.3	6.3	6.4	6.5	6.5	6.5	10:00 AM
"	6.5	6.6	6.6	6.7	6.8	6.8	11:00 AM
"	6.9	7.0	7.0	7.1	7.1	7.2	12:30 PM
"	7.1	7.2	7.2	7.3	7.3	7.3	1:30 PM
"	7.4	7.4	7.5	7.5	7.5	7.6	3:00 PM

TABLE 2. WEIGHTED AVERAGE FOR DISSOLVED OXYGEN

Date 1963	Area (ft ²)	DO x Area (ft ²) (mg/l)	Mean DO in River Cross-Section (mg/l)
7/25	373	2680	7.2
7/26	373	3200	8.6
7/29	373	1750	4.7
8/8	474	5540	11.7
8/13	472	3150	6.7
8/15	474	3720	7.9
8/21	474	2880	6.1
"	474	3040	6.4
"	474	3180	6.7
"	474	3360	7.1
"	474	3420	7.2
"	474	3450	7.5

FIGURE 3.
DISSOLVED OXYGEN PATTERNS
FOR RIVER CROSS-SECTION



During August 21, data was taken all through the day to see if the shape of the gradient would change. As can be seen on Figure 3, it did not change in shape but increased in magnitude from 9 AM to 3 PM.

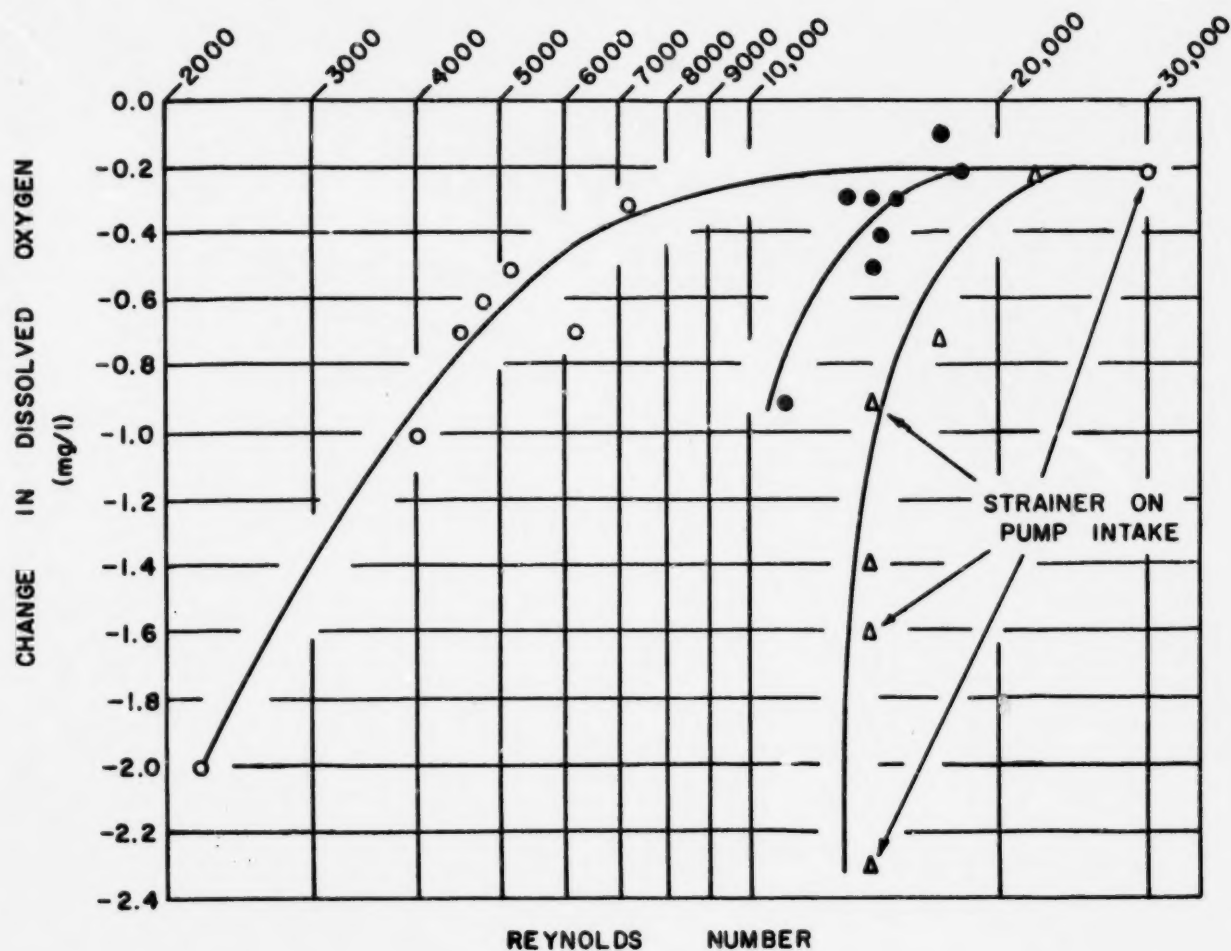
Using the mercury thermometer for measurement of temperature, there was no detectable variation throughout the cross-section. Water temperatures ranged from 22°C to 27°C during the overall test period. Measurements made with the conductivity meter failed to show any reproducible pattern across the stream. There was a statistical scattering of the data, but this was an inherent characteristic of the meter. If there was a variation, it was too small to be detected. During the period of testing, conductivity of the water ranged from 430 micromhos to 540 micromhos.

Figure 4 graphically presents the data obtained on the change in dissolved oxygen in the two pump and piping systems tested. The semi-logarithmic plot of the Reynolds number versus the change in dissolved oxygen from the river to the Field Test Station indicates a minimum satisfactory operating point of about 25,000.

There are three different plots because it was felt that the data fell into three distinct groups. This was an unexpected result. The explanation and correlation is that there was a rainfall in between the three sets of data (see Table 3) and this appeared to change the amount of oxygen-consuming material in the water and pipeline.

FIGURE 4.

CORRELATION BETWEEN REYNOLDS NUMBER
AND CHANGE IN DISSOLVED OXYGEN
FROM THE RIVER TO THE STATION



Δ — DATA FROM 7/26 TO 8/8
● — DATA FROM 8/9 TO 8/16
○ — DATA FROM 8/19 TO 8/26

TABLE 3. PIPELINE FLOW DATA

Date 1963	Reynolds Number	Dissolved Oxygen Manifold Deficiency (mg/l)
7/26	14,000	0.9
7/29	14,000	2.3
7/30	14,000	1.6
7/30	14,000	1.4
8/6	22,000	0.2
8/8	17,000	0.7
8/8	(Rain)	
8/9	17,000	0.1
8/12	18,000	0.2
8/14	14,000	0.5
8/14	15,000	0.3
8/15	14,500	0.4
8/15	14,000	0.3
8/16	13,000	0.3
8/16	11,000	0.9
8/19	(Rain)	
8/19	7,200	0.3
8/21	6,200	0.7
8/21	5,200	0.5
8/22	4,500	0.7
8/22	4,800	0.6
8/23	4,000	1.0
8/26	2,200	2.0
8/26	30,000	0.2

A perforated stainless steel strainer around the pump intake for four of the measurements did not seem to change the dissolved oxygen of the water pumped to the Field Test Station.

The temperature of the water increased an average of 0.5°F in traveling through the 400 feet of pipeline. This was primarily due to exposure of approximately 100 feet of the black polyethylene pipeline to solar radiation. Insulation, or burial, of this portion of piping could have reduced the change in temperature.

DISCUSSION AND CONCLUSIONS

Concentration of dissolved oxygen varied slightly across the river. A small cross-sectional gradient occurred that might stay the same during the day, but could change from day to day. It is felt that this gradient was caused by organic material that deposited on the bottom of the river. As this material built up, the gradient became more pronounced. On August 19, after two or three weeks without much rain, approximately one inch of rain fell and had the effect of scouring out the river and washing away most of the organic deposit. Two days later when cross-section data was taken, the DO varied only 0.2 mg/l across the river (see Table 1). Note that measurements on August 8 and 13 indicated a variation of 0.9 mg/l across the river.

The dissolved oxygen data obtained for the cross-section of the Little Miami River indicates a small variation in concentration linearly across the stream. No variation was detected in several samples taken at different elevations near the deepest portion of this shallow stream. Therefore, the weighted averages for dissolved oxygen shown on Table 2 represent mean values for this river as it flows past the Field Test Station. Referring to Table 1, it appears that a sample taken near the deepest portion of the river (Station #25) provided data at or near this mean value. The submersible pumps for the Field Test Station are located downstream from Station #22 to avoid interference with navigation on the stream. River water from this sampling point was 0.1 to 0.5 mg/l lower than the mean DO.

Some variation in dissolved oxygen concentration may be expected to occur across a stream. Each river and each location is unique and should be considered individually.

Special precautions should be taken in the design of pumping systems for water quality monitoring. To minimize change in dissolved oxygen concentration and temperature, the pipeline from the stream to the sampling apparatus should be sized to provide flow at a Reynolds number of 25,000 or higher. The pipeline should also be as short as practicable and thermally insulated.

APPENDIX

ELEVATIONS OF THE RIVER CROSS-SECTION BELOW
EACH OF THE STATION SAMPLING POINTS

Station	Elevation (ft)	Station	Elevation (ft)
1	494.7	25	454.8
2	492.2	26	455.2
3	487.7	27	455.3
4	483.7	28	455.8
5	479.3	29	455.9
6	474.9	30	456.0
7	474.5	31	456.1
8	473.8	32	456.4
9	474.0	33	456.5
10	473.8	34	456.5
11	474.1	35	457.0
12	473.8	36	457.8
13	465.2	37	458.4
14	462.9	38	458.8
15	459.2	39	459.7
16	458.6	40	464.0
17	458.1	41	467.0
18	458.3	42	465.4
19	458.0	43	476.3
20	456.5	44	480.3
21	456.4	45	484.0
22	455.9	46	488.2
23	455.3	47	492.3
24	454.5	48	494.4

APPENDIX

SAMPLE CALCULATION OF WEIGHTED AVERAGE
FOR DISSOLVED OXYGEN

Area (ft ²)		DO (mg/l)		(ft ²) (mg/l)
26.8	x	7.7	=	206
88.0	x	7.7	=	677
120.0	x	7.8	=	935
93.0	x	7.9	=	735
88.0	x	8.0	=	704
57.7	x	8.1	=	467
473.5				3724

$$\frac{3724.0 \text{ (ft}^2\text{)(mg/l)}}{473.5 \text{ (ft}^2\text{)}} = 7.9 \text{ mg/l}$$